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SPACE PHOTOGRAPHY FOR THE GEOGRAPHICAL STUDY OF THE EARTH

B. V. Vinogradov

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ABSTRACT

The article presents a historical review of the various means of space photography. These include photographs taken from research rockets (V-2, Viking, Aerobee), spacecraft (Mercury, Vostok, Voskhod and Gemini) and artificial Earth satellites (Tiros, Nimbus).

The author points out that the quality of the photographs is not as high as it could be, because none of the space vehicles was especially designed to photograph the surface of the Earth; this task was only an additional operation in the flight program.

Space photography is a method of recording the Earth's magnetic field by photographing it from vehicles flying beyond the Earth's atmosphere. /101*
Already available is a considerable number of space photographs of various terrestrial landscapes whose identifiable characteristics vary with the particular space vehicle and the photographic equipment used, the sensitivity of the

*Numbers given in margin indicate pagination in original foreign text.

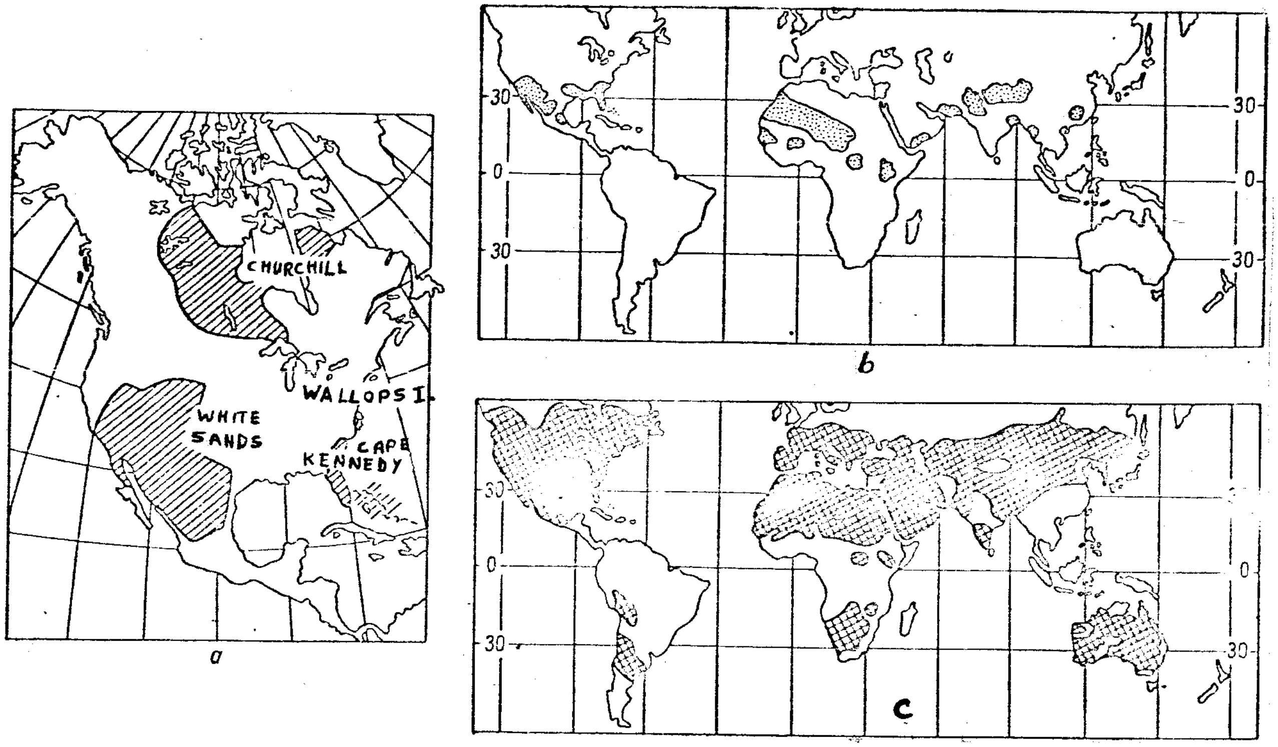

Figure 1. Areas covered by usable photographs. Photographs: a, from research rockets including nonorbital Mercury flights; b, from Mercury spaceships and c, from Tiros I, III and IV satellites (ref. 22). Usable space photographs are those that represent an image of the Earth surface from clouds not too oblique and with identifiable tonal variations.

photographic films, the altitude and direction of the optical survey axis, the illumination of the Earth's surface, the absence or presence of an overcast at the time of the photography and, finally, the method of transmitting the image to the Earth. In some areas of geographic research, such as climatology and oceanology, the space photographs have already found practical application, while in others, such as geology and biogeography, the methods for their effective utilization are still under investigation. Almost every type of terrestrial landscape from the Arctic to the tropics has been photographed from space (fig. 1).

This facilitates the first general conclusions on the possibilities and methods of developing space photography for the study of the Earth's geography (refs. 2-4, 6, 20, 22, 28 and 29).

Technical Aspects of Space Photography

The flight conditions of the rocket or satellite, the method of transmitting the image to the Earth, stability, periodicity and frequency of the photographic process play a particularly important part in space photography. All space photographs may therefore be divided into three groups according to the methods and facilities of their production: 1--photographs taken from research rockets, 2--photographs taken from orbital spaceships which deliver the pictures to the Earth, and 3--photographs taken from satellites regularly transmitting the images to the Earth through television channels. Information on the Earth's surface may be transmitted in the form of photographs, television images, geophysical data[1] and visual observations[2].

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[1]Sensitive receivers are capable of picking up the Earth's radiation on various wavelengths, from ultraviolet to radar. This waveband is considerably broader than the photosensitivity of the photographic materials, on the one hand, and it can be localized in any narrow optimum image area, on the other. Thus the measurement of a reflection in thermal waves is designed to produce information on the temperature differences of the Earth's surface reflecting the actual characteristics of the surface formations, and the lithological composition and humidity of the surficial deposits (refs. 7, 14). Furthermore, the infrared survey is an important supplement to photography, as it makes it possible to continue the observation of the Earth's surface at night. This review, however, is limited to the traditional methods of surface photography.

[2]Visual space observations are also made in addition to those listed above. It should be pointed out, without denying their value, that such observations, whether made by the naked eye or the use of various optical instruments, are limited as compared to the employment of photographic sensors. Successful visual observations of the Earth, however, were made by astronauts V. F. Bykovskiy, G. Cooper, A. A. Leonov, etc. and yielded some valuable information (the vari-colored water in the Bahama Islands area, the smog distribution in the San Diego area, etc.) before it could be learned from the photographs (refs. 20 and 23).

Space photographs of the Earth taken from research rockets

The first space pictures of the Earth were taken of the White Sands /102 proving Ground (New Mexico, U.S.) in 1945 from a V-2 rocket from an altitude of 120 kilometers (ref. 28). At least 36 V-2, Viking and Aerobee rockets (refs. 17, 21 and 26), designed to photograph the Earth, were launched from that proving ground in 1946-1958 (that is, before the launching of the Earth satellites). The rocket photographs were taken from an altitude of 100-150 kilometers. Many of the photographs were designed to trace the rocket's trajectory, and are therefore very promising; they also include a picture of the horizon. The program of photographs taken from rockets also included experiments in the selection of optimum parameters for future space photography from satellites. Thus the flight of the Viking-12 (1955) revealed that the infrared film used in photographing the Earth surface is less affected by the haze, and is potentially suitable for photography. The pictures produced by the ordinary aerophotographic cameras (such as K-25) were better than those taken with all other cameras used in space photography. This is not surprising, inasmuch as space photography is another version of aerial photography.

The scale of the pictures taken from the rockets ranged from $1/3 \cdot 10^5$ to $1/3 \cdot 10^6$. The actual resolving power was estimated by the pictures of the El Paso area produced by a K-25 aerial photographic camera from the Viking-11 rocket on an original scale of $1/10^6$ and magnified 7 times. It was found that such details as streets, railroad lines, canals and other linear objects not wider than 20-30 meters can be identified on space pictures with a rated resolution of about 200 meters. The following large objects were clearly visible on the pictures: the Sierra Nevada and Rocky Mountain chains, various rock outcrops on the Colorado plateau and lowlands, river basins and forests on mountain

Figure 2. A space photograph of the Rio Grande river area taken from the research rocket Aerobee launched from the White Sands grounds. The picture was taken on 17 June 1963, from an altitude of 161 kilometers; the camera used an infrared film, was equipped with f=150 mm, frame width 57 mm, and had 30° angle of view. The original scale was about $1/10^{6}$ (ref. 22). 1, Rio Grande river valley and cultivated fields in different conditions: the arid and harvested fields are seen as lighter areas, and the densely planted irrigated fields as darker areas; 2, upper terrace of the river and its valley borders; 3, high interior flat plains on ancient aeolian deposits with sandy and loam gray-brown soil and brush-covered steppes (of the Yucca and Bouteoua type) in Texas (U.S.); pictures of slight cumuli and their shadows are superimposed; 4, Interior upland on deluvial-proluvial deposits with creosote bush deserts (Larrea tridentata, Yucca and Opuntial species) in Chihuahua (Mexico); 5, brachy-anticlinal elevations and ridges 100-150 meters high with contrasting illuminated and dark slopes made up of argillaceous sandstone and marl of the Cretaceous period in the northwestern Sierra Madre submersion; 6, Piedmont sloping plains made up of proluvial trains with a clearly visible striated outline of temporary riverbeds; 7, enclosed argillaceous depressions, or playas; 8, the towns of El Paso, Ciudad Juarez and Islita; 9, Highways and railroad lines.

slopes, the Rio Grande riverbed and valley, and the snow on the mountains and elevations (fig. 2). A comparison of the pictures produced in repeated photography from the rockets made it possible to ascertain the phenology of the vegetation and dynamics of the snow cover. Following the launching of the artificial Earth satellites, the researchers naturally focused their attention on the identification of the photographs taken from space vehicles. But the pictures taken from the rockets did not lose their importance, especially in connection with local problems. Thus a new series of photographs were taken in New Mexico (in 1963) from the rocket Aerobee with a view to identifying the changes, on the basis of the space pictures, that had occurred in that area in the 15 years since it had been photographed from the first Viking rockets.

The following were also photographed from rockets in addition to the White Sands reservation: the firing ranges of Fort Churchill (Canada), Wallops Island (Virginia) and Cape Kennedy (Florida). Some of the rocket flights produced a clear image of the land surface, the cloud cover and floating ice. But the geographic value of such pictures was not very substantial (refs. 6 and 18). The space photographs taken from the Atlas rocket (in 1959), launched from Cape Kennedy in the direction of the Amazon river delta, contained a number of images of Florida marshlands, West Indian islands, and tropical forests in Brazil. Successful pictures of the subarctic regions were taken from Aerobee-type rockets (1960) launched from Fort Churchill. Those rockets photographed the cloud systems, the snow and ice cover, the geological structure of the Canadian shield 104
and the lakes, forests and tundras as they looked in the spring and autumn (ref. 8).

Photographing the Earth From Spacecraft

Pictures of the Earth have been taken from orbital spacecraft since 1960 under the Mercury (U.S.), Vostok and Voskhod (USSR) and Gemini (U.S.) flight programs. The suborbital flights of the MR-1 (1960), MR-2 and MR-3 (1961), like the research rockets, produced pictures of limited areas of Florida, the Bahamas and the Atlantic ocean (refs. 6 and 24). The orbital flight of the space station MA-4 (1961) brought the first satisfactory series of photographs of the Earth. That station photographed the strip from Florida to Lake Rudolph, and produced good pictures of the Earth's surface between the Moroccan coast and Lake Chad (refs. 22 and 24). Shown in those pictures were southern Morocco, the Algerian part of the Sahara, southern Libya and the northern part of Niger. 1106
Clearly identifiable on the space pictures is the distribution of various rocks, their dislocation, the longitudinal and transversal dunes of the Big Erg deserts, the large wadis, the Dra rocky deserts (hammads), the Melrir solonchak depressions (sebhas), the Atlas foothills, the Ahaggar island mountains and a number of other landscapes (fig. 3). The zonal changes of the Sahara desert areas to the Sahel arid and wooded steppes and savannahs can be identified in the southeastern pictures taken along that route.

The pictures from Mercury 6, 7, 8 (1962) and 9 (1963) were taken by the astronauts themselves with small (70 mm) manually operated cameras. A very clear picture was produced by the Maurer and Hasselbad camera on a $1/2 \cdot 10^6$ to $1/5 \cdot 10^6$ scale. The initial conclusions to the effect that color films would not be suitable for space pictures of the Earth (ref. 16) were not justified. The colored photographs taken from the Mercury and Voskhod spaceships were satisfactory, and only slightly affected by the haze and diffused blue light.

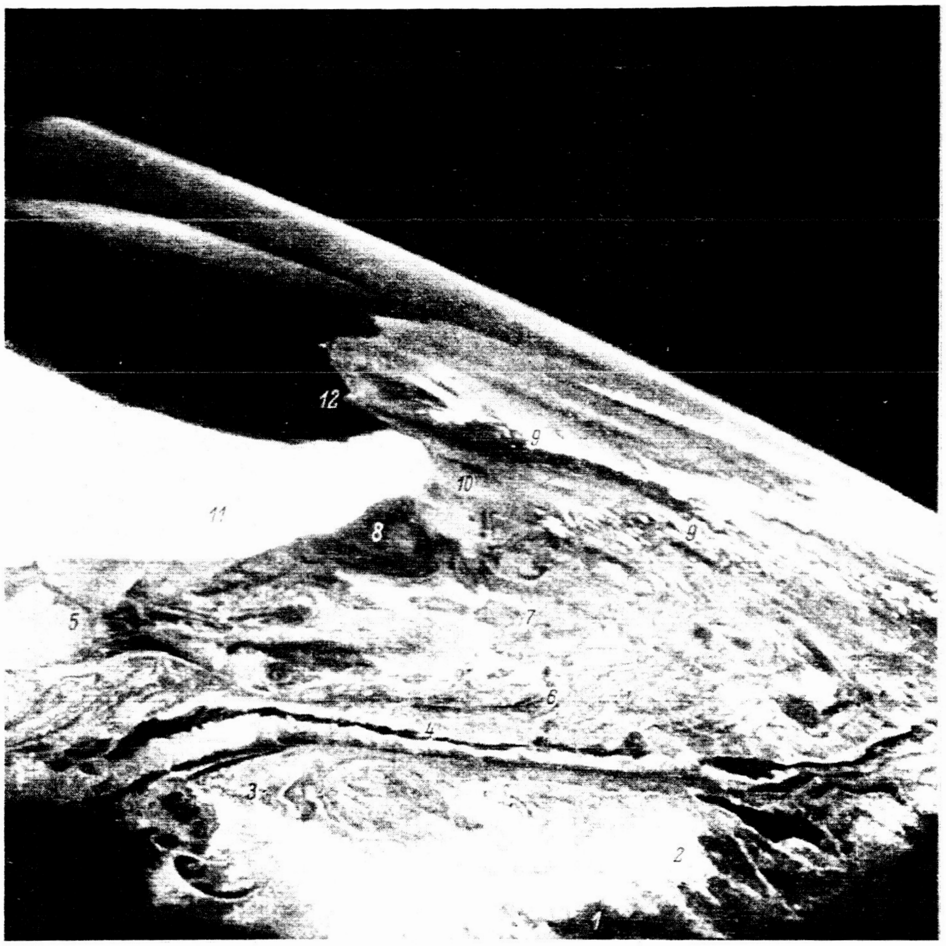

Figure 3. A photograph of southwestern Morocco taken from the Mercury-4 spacecraft. Taken on September 13, 1961 from an altitude of 163.8 kilometers, with a Maurer camera using an Anscochrome color film; each frame measures 70 x 70 mm, f=75 mm, angle of view 45°, optical axis tilted 72° to the northeast. Original scale of foreground $1/22 \cdot 10^{5}$ (ref. 28). 1, Northern fringe of the Dra hammad (dark gray field crisscrossed by light wadis lines) - a rocky desert on limestone and conglomerates covered with dark desert varnish and extremely sparce suffruiticose and lichen vegetation; 2, accumulation-denudation piedmont (figure caption carried over to following page)

plain (Sahara piedmont) made up of contemporary (lighter tones) and ancient (darker tones) argillaceous-pebbly proluvium with herbacesous-suffruiticose subtropical semideserts (Aristida and Zizyphus species); 3, hinge structure made up of stratified rocks of the Carboniferous period (gray tones with curved banding); 4, low (relative altitude 200 meters) Jebel Warkeiz is made up of heavy sandstone of the Carboniferous period (the contrast of the southern and northern slopes is visible).

5, maritime plain on alluvial-deltaic and aeolian deposits with bush-covered deserts--Euphorbia, Lycium and Rhus species (light-gray smooth tone with a dark line of the Dra wadi bed); 6, a srip of hills and ridges at the western and of Jebel Bani made up of of argillaceous sandstone of the Silurian period (darkish gray tone with prominent fine parallel banding; 7, Intermontane depression of the Ifni river valley made up of shale and other soft rocks of the Cambrian period with semidesert thin forests (Argania spinosa); brachy-anticlinal arched structures are visible (elliptical) patches with their axes oriented to SW--NE); 8, Archean typhon in the Ifni area with xerophytic wood plants and brushwood vegetation (dark tone); 9, mountain ranges with coniferous forest vegetation (Pinus, Juniperus and Cedrus species) indicated by ridges of cumuli; 10, Maritime plain of the Sus wadi with alluvial-marine deposits; 11, low layer clouds above the sea coming to an abrupt end along the coast line; 12, Cape Gir.

About 25 space pictures of the land were taken during the MA-5 flight; landscapes of western Sahara, strips of dunes and the area between the deserts and the savannah in the lower part of the Senegal river basin, the river drainage and Alpine topography of northwestern Mexico, the east and southeast of the U.S. with a picture of the river drainage, the distribution of woodlands and forms of land utilization. The pictures taken during the MA-6, MA-7 and MA-8 flights also included a small number of land areas free of clouds in Oceania, northwest and west Africa, Florida, northeastern U.S., the west coast of Mexico, the coast of the Gulf of Mexico (refs. 6, 24), etc. A more successful flight was made by the MA-9 (1963) with astronaut Cooper who took about 30 good pictures of North Africa, Arabia, Iraq, India, Tibet and the Philippines. Easily identifiable on those pictures are the relief, geological structure, glaciers, the snow cover, types of land, the drainage course in the deltaic parts of the seas, and many other features.

Photography from artificial Earth satellites

Artificial Earth satellites can photograph the Earth continuously and transmit the pictures to receiving stations by television. The eight satellites used in the Tiros (Television and Infrared Observation Satellite) program (before 1965) were launched in such a way that every area of the Earth was within the viewing field of at least one of the satellites (ref. 27). The only shortcoming of that system was the equatorial direction of the satellites' orbits which prevented them from covering the entire area of the Earth and limited them to 65° northern latitude and 65° southern latitude. The television receivers of the Tiros systems were sensitive to light within the wavelength range of 0.45 to 0.8 micron. which corresponds to the sensitivity of panchromatic and infrachromatic photographic films (ref. 11). The pictures were taken from a 650-850 kilometer altitude with medium-angle cameras on a very small scale of $1/12 \cdot 10^7$ to $1/24 \cdot 10^7$ with each frame measuring 6.3 x 6.3 mm, and with narrow-angle cameras on a scale of $1/7 \cdot 10^6$ to $1/20 \cdot 10^6$ (Tiros I and II). These frames produce a picture of an area up to 1,000 km^2. The resolving power of the images was generally low, about 3 km, and only the images produced by the narrow-angle cameras of Tiros I and II revealed a resolving power of 0.3 km. The resolving power of the latter was comparable to that of the pictures brought to Earth by the spaceships, but this was achieved by reducing the surveyed area to 100 km^2. This drawback was so great, inasmuch as it made photogrammetric bridging difficult, that the use of narrow-angle cameras had to be discontinued in the following Tiros satellites. But it is precisely the pictures taken from Tiros with narrow-angle cameras that are highly valuable for purposes of geographical identification.

Several hundred thousand pictures were taken from the Tiros satellites, but /1107 only a small number of those photographs (less than 1 percent) are suitable for the study of the land surface (ref. 6). The overwhelming majority of the photographs taken from Tiros are images of the cloud cover or the ocean, and are too oblique and lacking in contrast; their transmission to Earth was hampered by static and interference, and it is difficult to key them to the appropriate terrain. Despite the low resolving power, it is still possible to distinguish on the Tiros-transmitted images the structure of the cloud systems, the ice sheet, various forms of the macro- and meso-relief, large features of the /1108 geological structure, certain types of vegetation, the contours of the river drainage, glaciers, lakes and the snow cover (fig. 4). Such systems are particularly effective in the study of the rapidly changing rhythmic and even catastrophic landscape components, such as the movement of air masses (refs. 9 and 13), the changing ice sheet (ref. 31), the dynamics of the snow cover (ref. 10), the

Figure 4. Picture of eastern part of Lake Issyk-Kul' and adjacent territory taken from Tiros-1 on May 21, 1960, with a narrow-angle camera (12.7°) with a focal distance of 40 mm; the picture frames measured 6.3 x 6.3 mm, the original scale was $1/17\cdot10^6$ to $1/19\cdot10^6$, the direction was close to vertical, and it was transmitted to Earth by the automatic television transmission system (APT) (ref. 22). 1, Lake Issyk-Kul': deep parts (a, over 50 meters, even dark tone), shallow parts (b, even gray tone); 2, coastal and gently-sloping food hill zone of stipa-wormwood steppes (and mesophytic leaf-shedding brushwood steppes of the xeromorphic plant type) on proluvial and alluvial-proluvial loess-like deposits, much of it used for dry and irrigation farming up to 2,200-2,300-meter altitude; 3, river valleys on the (figure caption carried over to following page)

foothill plain with meadow-type coastal vegetation (rivers Tyup, Dzhargalan, etc.); 4, deeply incised intermontane consequent river valleys of the northern slopes of the Terskey-Alatau mountain range with meadow steppes and coniferous forests (mostly Tien Shan spruce) to an altitude of 2,600 (3,000) meters; 5, deeply incised intermontane river valleys of the southern slopes of the Terskey-Alatau mountain range with meadow, stipa-wormwood and brushwood steppes at the same levels; 6, mountain stipa-wormwood steppes and cushion plants (podushechniki) of the Naryn river basin up to 3,000-meter altitude; 7, subalpine belt of mountains and elevated watersheds with subalpine meadows and thin forests, highland steppes and cushion plants, talus and base rock outcrops up to an altitude of 3,500-3,700 meters; 8, Alpine belt with alpine meadows, alpine cushion plants, snow cover (permanent above 4,000-4,400 meters) and small glaciers on the Kungey Alatau, Terskey-Alatau, Akshiyrak and Kuilyutau mountain ranges; 9, areas of continuous (a) and variable (b) cloudiness.

outbreak of large-scale fires (ref. 29), floods, etc. The Nimbus program, whose first satellite was launched in a subpolar orbit in August 1964, is expected to produce still more practical results. The pictures from Nimbus are supposed to have a higher resolving power, always vertical and cover the entire Earth, at least in the course of 24 hours (ref. 6). At night the pictures are taken by infrared radiation detectors through the window of atmospheric transmission of about 4 microns (ref. 1).

The Advantages of Photographing the Earth from Space

Photographing the Earth from space is, in effect, superhigh (50 km and higher) and supersmall-scale aerial photography, and the development of space photography is based on the use of the technical facilities and methods of aerial photography.[3] They are all intended to provide general geographic information in three directions.

Horizontal Integration

The main advantage of space photography is the wide view of the terrain and the territorial generalization of the structure of the natural features. A space photograph can cover an area of several thousands, tens and even hundreds of thousands of square kilometers. On such pictures it is possible to trace the large regional and global structures, find the relation between remote features and study the zonal patterns which are inadequately explained not only by ground observations but also on ordinary aerial photographs. The attempts to imitate space pictures (scale $1/10^6$) by a multiple reduction of the

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[3]If in previous years aerial photography was confined to the "traditional" scales of $1/10^4$ to $1/5 \cdot 10^4$, the recent trend has been toward "multi-scale" photography (ref. 30). Under development, on the one hand, is a super large-scale photography, $1/10^3$ and larger (to $1/10^2$), from helicopters, balloons and mobile towers reflecting the forms of individual plant crowns, the structure of phytocoenoses, etc. (ref. 25). Experiments are being made, on the other hand, in super small-scale aerial photography, $1/10^5$ and smaller, from high-flying planes and stratosphere balloons with a view to reproducing large structural features of the Earth's surface (refs. 12 and 15).

mosaic assembly consisting of small-scale aerial photographs (scale $1/5\cdot10^4$) were not successful: the tonal differences on them were found to have been distorted by the multiple reproduction. Furthermore, such an operation would have required the compilation of a colossal number of accurate composite photographs which is practically impossible in a number of territories.

The horizontal integration on space photographs, in addition to covering a large area, also facilitates their small-scale reproduction. The original scale of the pictures of the Earth taken from space ranges from $1/3\cdot10^5$ to $1/2\cdot10^7$. On such scales the features of the Earth's surface are generalized and certain details are eliminated, and we get an image of the large structural features of the Earth's surface. The generalization of large-scale topographic maps by the usual cartographic methods for the purpose of producing small-scale general maps involves so many stages that the latter, as a rule, lose their specific characteristics. Territorial generalization, based on the photographic image, will make it possible to objectify the process of compiling small-scale special maps just as it is done in the compilation of large-scale maps of the basic aerial photographs.

Vertical Integration

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Aerial photography has long been used for the purpose of grouping the information on various components of the lithosphere, biosphere and hydrosphere of the landscape by integrating their images on one aerial photograph into a definite natural complex. The only drawback of aerial photography has been that the climatic sphere components (with the exception of certain microclimatic conditions) are left out of the complex image of the landscape on the aerial photograph. The use of space photography makes the complete integration of all the landscape components--from the geological structure to the upper layers of the atmosphere--possible for the first time. The relation between the structure of the cloud cover (and the accompanying meteorological conditions) and the surface has already been identified in a number of cases. A clearly defined boundary of continuous cloud layering above the sea and cloudless conditions above the continent can be seen along the west coast of Africa where the relatively cold ocean masses of the Canary antitrade wind current come in contact with the tropical deserts of southern Morocco, as shown in figure 3, for example. The cumulus extending above the land, on the other hand, is confined to the Atlas mountain ranges. The connections between the other landscape components can also be traced on the space photographs: between the distribution of the snow cover and the topography; the arrangement of the fault, intrusive and fold geological structures; the distribution of the vegetation, forms of land utilization and the structure of various landscapes.

Dynamic Integration

The presence of permanent orbital space stations makes it possible to get pictures of any illuminated part of the Earth at intervals ranging from several minutes and hours to months and years. A comparison of repeated photographs will facilitate the study of the dynamics and rhythm of the natural processes on vast territories. The repeated pictures taken by the same photographic pictures are highly comparable. The photographs taken from satellites by the television method can be used for the study of rapidly changing landscape components and catastrophic phenomena (the movement of cyclones and fronts, the dynamics of the snow cover and ice sheet, manifestations of volcanic activity, the extent of large forest fires, floods, etc.). Photographs returned to Earth from the rockets and spaceships are used in the study of the seasonal and perennial vegetation dynamics and the forms of land utilization.

Some Technical Advantages

A number of technical advantages of space photography over aerial photography should be pointed out. The lack of external vibration which sharply reduces the actual resolving power of the photographs taken from planes facilitates the production of pictures with a high resolution. Aerial cameras with infinite focal length lenses (up to several meters) can be installed in satellites inasmuch as their dimensions do not interfere with the motion in outer space. This would make it possible to increase the ground-surface resolution and take pictures on 1:50,000 scale (ref. 19). The quality of the super small-scale pictures taken with long focal length cameras is improved by the more even illumination of the negative. Taking into consideration the large areas and the frequency of the picture-taking process, it would be reasonable to expect a low cost of individual space photographs even if the cost of launching itself is high. Finally, the presence of orbital space stations transmitting images to the Earth makes it possible to get the "freshest" picture of any illuminated part of the globe not covered by clouds upon the first demand of the researcher. Thus in the U.S. they have already established a system of shipping the rolls of films of the Earth photographed from TIROS to the clients (ref. 6).

Conclusions

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In conclusion we must dwell on the shortcomings of space photography and some of the problems involved in its development from the viewpoint of geographic research.

To begin with, the most serious drawback of space photography as a whole should be emphasized: not a single one of the space vehicles (with the exception of the Arctic Meteorology Photo Probe Program) was especially designed to photograph the Earth's surface, and all pictures taken from them were part of an additional operation in the flight program. This is why the quality of the space photographs of the Earth's surface is still not very high. The quality of the space pictures could be improved by the use of the somewhat modernized standard aerial cameras and films currently employed in aerial photography. The trend in the development of space photography is toward a ground-surface resolution of details not exceeding 20 meters; to produce well-planned photographs designed to meet the requirements of stereophotogrammetric processing; to ensure a continuous and regular transmission of images. It would be desirable to have the geographic images of the Earth transmitted from the satellite through television channels for a preliminary identification, and also to have them delivered periodically to the Earth in containers. In view of the fact that the photographic study of the Earth's surface is highly complex and specific, a special "geographic" Earth satellite should be created and its required functions outlined.

The characteristic feature of space photography is the rapid transmission of a considerable number of Earth pictures with a vast amount of diverse information. The reception of space photographs involves the use of complex technical devices. They cannot be identified fast enough, and their information cannot be adequately utilized, by the usual visual methods. The rapid identification of space photographs requires, first of all, the development of a system of photo keys on a $1/10^4$ to $1/2 \cdot 10^5$ scale, based on small-scale aerial photographic materials, that could be used for referencing and the original identification of space photographs. Also, the development of identifying microphotometric devices facilitating a more detailed analysis of the space photographs.

Finally, the space photographs should be carefully systematized in view of their unique characteristics. Many of the them are valuable only if they can be used immediately after their transmission or delivery to the Earth. We must see to it that space photographs (as well as aerial pictures) are used on a wide scale and submitted for close identification to various specialists.

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